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DEVIATIONS OF THE SUN'S GENERAL MAGNETIC FIELD FROM THAT OF A UNIFORMLY MAGNETIZED SPHERE

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A communication to the Academy in 1917[1] describes the method used for the location of the sun's magnetic axis and gives values for the inclination, the period of revolution about the solar axis of rotation, and the epoch when the magnetic pole was on the central meridian. These results were based upon observations made on 63 days between June 8 and September 25, 1914. In the meantime the spectrograms of 11 additional days within the limits of this interval have been measured and reduced, and the elements defining the position of the axis have been revised with the following results (appended quantities are probable errors):

$$i = 6\overset{\circ}{.}0 \pm 0\overset{\circ}{.}4, \quad P = 31.52 \pm 0.28 \text{ days}$$
$$t_0 = 1914, \text{ June } 25.38 \pm 0.42 \text{ days, G. M. T.}$$
$$k = 0.99 \text{ (a constant inversely proportional to the polar field-strength)}$$

The modifications produced by the revision are unimportant, and, so far as the 1914 series of observations is concerned, these values may be accepted as final.

The uncertainty in the period is naturally large, for it has been derived from data covering less than four complete revolutions of the magnetic axis. Moreover, this limitation prevents any conclusion as to the constancy of the period. An improvement of the results in these particulars therefore requires additional observations, which should be distributed over a long interval. A beginning in this direction was made with a short series in September, 1916, which should reduce the uncertainty in the period well below a tenth of a day and make it possible to carry the longitude of the pole forward, without ambiguity as to the number of revolutions, to the coming sun-spot minimum, when further observations can be undertaken wihout risk of interference from the magnetic fields of spots.

The 1916 observations are now under discussion, and the indications are that the longitudes to be derived from them will agree closely with those calculated from the 1914 results. The period given above is therefore probably near the true value.

All discussions thus far described rest upon the assumption that the sun's general field is that of a uniformly magnetized sphere. The example of the earth, however, suggests that this hypothesis may be justified only to some rough degree of approximation, and that the field may not possess the uniformity hitherto presupposed.

We have therefore rediscussed the data from this standpoint, with results which seem to be conclusive. The investigation has had to meet the difficulty that the percentage errors in the data, in the nature of the case, are large; but there seems no doubt that there are irregularities in the field-strength at least, which cannot be accounted for on the basis of systematic or accidental error.

In order that the numerical quantities involved in the above solution—which we may refer to as the uniform-field solution—might be utilized as completely as possible, we have based the discussion upon the formulae there used, namely,

$$\left.\begin{array}{c} Ax + By = \Delta \\ x = k^{-1}\cos i, \qquad y = k^{-1}\sin i\cos\lambda \\ Y = y/x = \tan i\cos\lambda \end{array}\right\} \tag{1}$$

A and B are known quantities, functions of the heliographic latitudes of the sun's center and the points observed; Δ is the observed displacement of the spectral line; and i and λ are the inclination of the magnetic axis and the longitude of the magnetic pole. Y is a function of i and λ, whose value is calculated for each day from all the measured Δ's for that day. The discussion of the resulting series of Y's then leads to the required values of i, t_0, P, and finally to k, which is connected with H_p, the field-strength at the ple, by the relation

$$k = \frac{4}{CH_p}, \tag{2}$$

in which C is a constant depending on the spectral line employed.

For the uniform-field solution, the values of Y were calculated separately for three different lines. For the investigation of the deviations from the uniform field, the measures of the three lines were combined (this is possible since the values of x for the three lines are sensibly equal) and the entire collection of data then subdivided according to zones of heliographic latitude as follows:

I $\varphi > +10°$
II $+10° \overset{=}{>} \varphi \overset{=}{>} -10°$
III $\varphi < -10°$

The outer limites for forces I and III vary somewhat, but are approximately 45°.

To the data within these limits we have applied equations (1), much as described above. In other words, we have derived separate uniform-field solutions for each of the zones. Had the three series of results agreed within the uncertainties affecting their determination, we could only have concluded that there is no evidence for the existence of appreciable deviations from the uniform field originally presupposed. As a matter of fact, we have found a large difference for k, which leads to the conclusion expressed above.

Certain details require comment. The fundamental equation—the first of (1)—cannot be applied directly to either zones I or III, because of the numerical values of the coefficients A and B. There is no change in algebraic sign and the range in their values is so small that the simultaneous determination of x and y becomes practically indeterminate. For the middle zone the conditions are more favorable, but even here it has not seemed advisable to attempt a direct solution. Since the quantity x, as shown by the uniform-field solution, is apparently constant throughout the entire interval, we have preferred to solve by successive approximations, beginning with an assumed value of x.

We therefore write the fundamental equation in the form

$$B \tan i \cos \lambda = \Delta x' - A, \tag{3}$$

where for convenience $x' = k/\cos i$ has been substituted for $1/x$. The value of x' from the uniform-field solution is 1.00, and this we use for the first approximation in deriving $Y = \tan i \cos \lambda$ from (3). We have for each zone, from all the data for each day, the normal equation

$$[BB] \tan i \cos \lambda = [B\Delta]\, x' - [AB] \tag{4}$$

The individual values of Y are presumably in error, because of the assumed value for x'. It is easily shown, however, that neither the phase nor the period of the curve $Y = \tan i \cos \lambda$ is thereby affected. The entire effect goes into the amplitude. Using the first approximation for x', we can therefore determine t_0 and P for each zone, free from error, exactly as in the case of the uniform-field solution. The curves for Y show that the results in each case are sensibly the same as those previously found, and we therefore adopt for each zone the values given above.

Since the weight of tan i cos λ given by (4) is $[BB]$ the normal equation for tan i is

$$\tan i\, \Sigma\, [BB] \cos^2 \lambda = x'\, \Sigma\, [B\Delta] \cos \lambda - \Sigma\, [AB] \cos \lambda \tag{5}$$

where the outer summation symbol covers all the separate days. With this equation we find for the three values of i

$$\text{I} \quad 4\overset{\circ}{.}9 \pm 0\overset{\circ}{.}7; \qquad \text{II} \quad 6\overset{\circ}{.}7 \pm 0\overset{\circ}{.}5; \qquad \text{III} \quad 3\overset{\circ}{.}7 \pm 1\overset{\circ}{.}0 \tag{6}$$

With the aid of these values we now determine from the measures of each day a new approximation for x', using the normal equation

$$[\Delta\Delta]\, x' = [A\Delta] + [B\Delta] \tan i \cos \lambda \tag{7}$$

which is at once derived from the fundamental equation. Noting that the weight of each x' is $[\Delta\Delta]$ and combining the different days, we have for the mean x'

$$x'\Sigma[\Delta\Delta] = \Sigma[A\Delta] + \tan i\; \Sigma[B\Delta] \cos \lambda \tag{8}$$

The results of the second aproximation for x' are

$$\text{I} \quad 0.97 \pm 0.009; \qquad \text{II} \quad 0.60 \pm 0.018; \qquad \text{III} \quad 0.96 \pm 0.008 \tag{9}$$

It thus appears that for zones I and III the original assumption was nearly correct; for the second zone, however, the change in x' is large.

For the further approximations we have from (5) and (8), respectively,

$$d(\tan i) = \alpha dx' \tag{10}$$

$$dx' = \beta d(\tan i) \tag{11}$$

where

$$\alpha = \frac{\Sigma\,[B\Delta] \cos \lambda}{\Sigma\,[BB] \cos^2\lambda} \qquad \beta = \frac{\Sigma\,[B\Delta] \cos \lambda}{\Sigma\,[\Delta\Delta]} \tag{12}$$

For zones I and III, α and β are small quantities of the order of 0.01 or 0.02, and since dx', the differences between the first and second approximations for x', are only -0.03 and -0.04, respectively, equations (10) and (11) show that the corresponding values of i and x' given in (6) and (9) are final.

For zone II, $\alpha = 0.120$ and $\beta = 1.42$. We have found already, in order, $x'_1 = 1.00$, $\tan i_1 = 0.118$, $x'_2 = 0.60$, whence $dx' = -0.40$; and by successive substitution into (10) and (11) we derive $\tan i_2 = 0.070$, $x'_3 = 0.53$, $\tan i_3 = 0.062$, $x'_4 = 0.52$, $\tan i_4 = 0.061$. As no further change is produced by additional substitutions, x'_4 and $\tan i_4$ are adopted as the final values.

Calculating k from x' and collecting results, we have

$$\begin{array}{llll} \text{For } \varphi & = 45^\circ \text{ N to } 10^\circ \text{ N}, & i = 4^\circ\!.9, & k = 0.96 \\ & = 10 \text{ N to } 10 \text{ S}, & = 3.5, & = 0.52 \\ & = 10 \text{ S to } 45 \text{ S}, & = 3.7, & = 0.96 \end{array}$$

$$P = 31.52 \pm 0.28 \text{ days}$$

$$t_0 = 1914, \text{ June } 25.38 \pm 0.42 \text{ days, G. M. T.}$$

The uncertainty in the inclinations averages about $0^\circ\!.7$, while that in the k's is one or two units of the second decimal. Since the inclinations, periods, and epochs for the three zones are sensibly the same, the deviations from a uniform spherical field within the region from 45° N. to 45° S. are apparently restricted to the polar field-strength, which is inversely proportional to k. Here the variation with latitude is unexpectedly large—far greater than the uncertainty of the calculation. Unless the observations are affected by a large systematic error, which is itself a rather complicated function of the magnitude of the observed displacement Δ, the change must be real.

The measures have all been made with the parallel-plate micrometer and it is difficult to believe that errors of the kind required to make the result illusory can have entered. Our experience would lead us to believe that important variations in the field-strength of the character indicated actually exist.

It is unexpected to find the i's for all the zones smaller than that from the uniform-field solution. It is easily seen, however, that the two series of results stand in the proper relation to each other. In the uniform-field solution the displacements within the limits of zones I and III contribute about fifteen times as much to the weight of k as do those in zone II. The mean result for k should therefore be sensibly the same as the values for zones I and III when treated separately, as proves to be the case (k = 0.99, 96, and 96, respectively). The weight of the inclination, on the other hand, is derived largely from the observations of the equatorial zone. Moreover, i is calculated after k has been found, so that the conditions in the uniform-field solution are analogous to those of the first approximation of zone II. In this approximation the equatorial observations combined with $x' = 1.00$—the equivalent of $k = 0.99$—gave $i = 6^\circ\!.7$, which is nearly the same as the value found from all the data. The measures of zones I and III combined with $k = 0.99$, as we know from the zonal analysis, must lead to relatively small values for i, amounting to about 4°. The mean therefore lies between these two extremes, with a preponderance of weight in zone II. This accounts for the value of $6^\circ\!.0$ originally found—a mean result which is in excess of all the inclinations found by treating the zones separately. It is only when the equatorial observations are discussed by themselves that the true value of k for this region reveals itself or has any appreciable influence upon the solution; but when once found the inclination is necessarily decreased.

We are under great obligation to Miss Wolfe of the Computing Division who has rendered much assistance with the extensive numerical calculations required for the discussion of the data.

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[1] Seares, F. H., van Maanen, A., and Ellerman, F., these PROCEEDINGS 4, 1918, (4–9).

ON THE PROBLEM OF THE PRODUCTION OF FAT FROM PROTEIN IN THE DOG

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In eight experiments in a series of thirteen, after giving meat in large quantities (700 to 1300 grams) to a dog weighing 11 kgm., the respiratory quotients during the height of protein metabolism were between 0.793 and 0.800. A calculation showed that under these conditions the retained carbon residue of the protein metabolized was held back in such a form that, had it been oxidized, the respiratory quotient of this retained pabulum would have been 0.85. This would represent the oxidation of material half of whose calories were composed of fat and half of carbohydrate. The dog showed quotients of 0.82 and above only after the larger quantities of meat were given (1000 grams or more). It was extremely difficult to induce the dog to take meat in sufficient quantity to indicate a considerable production of fat from protein. Incidentally it was observed that the basal metabolism of a dog fed with meat in large quantity for a time and then caused to revert to a 'standard diet'